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TRANSCEIVER MULTICOUPLER

Harvey L. Landt

Collins Radio Company

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SEMIANNUAL REPORT

By
H. L. LANDT

DECEMBER 1972

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13. ABSTRACT

This semiannual report covers the initial progress on a program to develop an exploratory developmental model of a transceiver multicoupler in the 30- to 80-MHz frequency range. The theoretical development and analysis leading to a satisfactory design for the multicoupler is presented. Experimental laboratory data is presented to support the theoretical development. Schematics and drawings to support the overall design concept are included. Curves and data showing the computed performance of the 10-channel transceiver multicoupler are also presented.

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Foreword

The author acknowledges the efforts of Mr. Don Mooty of Collins Radio Company in preparing the computer programs used in analyzing the multicoupler performance. Curves presented in this report were generated using the Complot Generalized Plotter Routine, PCMP29.

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General Considerations

This development covers the design, fabrication, and test of a multicoupler that permits up to 10 transceivers to operate from a single broadband antenna over the frequency range of 30 to 80 MHz. Electronics Command Development Specification DS-EH-0044A (A) dated 28 April 1971 describes the required multicoupler.

The decoupling resonator multicoupler approach, as originally proposed, has been discarded due to the difficulty of designing the decoupling resonator in the allowed volume. For resonator unloaded Q's in the order of 500 to 1,000, it can be shown that the on-frequency to off-frequency (5-percent spacing) impedance ratio is approximately 100. For good performance an impedance ratio of 1,000 would be desirable. For the allowed volume this ratio could be achieved for a frequency ratio in the order of 15 percent. Since a 5-percent frequency spacing (40-dB point) is mandatory, the design activity has centered on a parallel connected multicoupler approach. A technique for connecting the output of 10 filters to a common junction with a minimum of interaction has been developed.

The filter design for each channel is the same as proposed. A minimum-loss, 3-resonator filter is employed in each channel of the multicoupler. Each resonator of the filter consists of a capacitively tuned helical resonator.

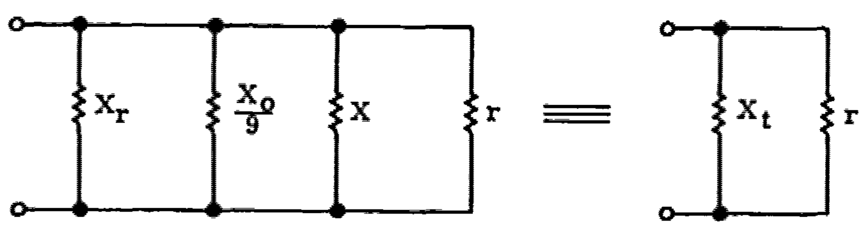
Two basic problems require a solution to achieve a suitable multicoupler design.

1. Fixed coupling structures are required to achieve a practical, tunable filter. These coupling structures, however, must provide the proper degree of coupling as the filter is tuned over the entire operating frequency range. In this case (constant percentage bandwidth requirement) the desired coupling should provide a constant coefficient of coupling (internal couplings) and a constant terminal Q (external couplings) as the filter is tuned.
2. The output coupling must be designed so that the filter outputs can be connected together to form a multicoupler.

Output Coupling Considerations

The output coupling must load the output resonator to a nearly constant terminal Q (Qt) as the filter is tuned from 30 to 80 MHz. The coupling must possess sufficient physical length to allow 10 filters to be grouped around the common junction point. The coupling must be such that the shunting reactance of the off-channel branches has a reasonable value with respect to the on-channel resistive component at the junction.

Preliminary calculation indicated that the above conditions might be met by using a transmission line for the output coupling element, provided the line is used as an impedance transformer to give the proper reactance to resistance ratio at the junction. If a transmission line having a Zo of 50 ohms is employed, the impedance level coupled into the output resonator must be in excess of 500 ohms. Laboratory investigation showed that the desired terminal Q (59) could not be achieved with loop coupling at the 500-ohm level. Tap coupling, however, could provide the proper loading. The total junction impedance is shown in figure 2-1. The total impedance is composed of four elements in parallel. Xo represents the reactance of an off-channel branch. Since one of the channels of the multicoupler is on frequency in this analysis, the remaining nine channels form a total shunting reactance of Xo/9. The equivalent circuit of an off-channel branch is shown in figure 2-2. The circuit consists of a connecting transmission line having a characteristic impedance of Zo_L and a quarter-wave resonant frequency of fo_L. The line is terminated in the off channel impedance of a filter (X_{off}). This off-channel filter impedance is assumed to be the portion of the helical output resonator from the tap point θ_t to ground, the helical resonator having a characteristic



$$X_t = X_r \left\| \frac{X_o}{9} \right\| X$$

Figure 2-1. Total Junction Impedance.

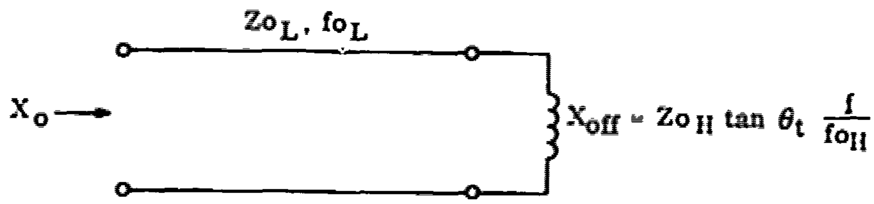


Figure 2-2. Equivalent Circuit of an Off-Channel Branch.

impedance of Zo_H and a self-resonant frequency of fo_H. Again, laboratory measurements confirmed that approximating X_{off} in this manner is a valid assumption.

The on-channel branch gives two components to the total junction impedance, namely, X and r. Where X is the residual reactance presented at the junction and r is the resistive component at the junction. The equivalent circuit of the on-channel branch is shown in figure 2-3.

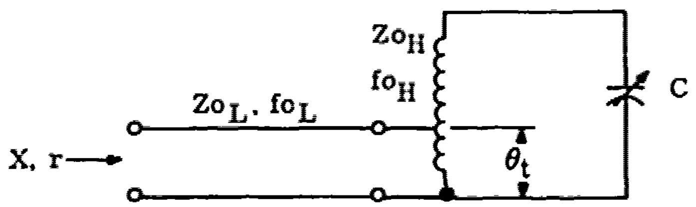


Figure 2-3. Equivalent Circuit of an On-Channel Branch.

The circuit consists of a connecting transmission line (identical to those in the off-channel branches) tapped into the output resonator at θ_t. Capacitor C tunes the output resonator to the on-channel frequency.

A compensating reactance (Xr) is added to the junction so as to resonate the junction at the mean of the 30- to 80-MHz band. In this case a capacitor is required to resonate the junction since the transmission lines and X_{off} are inductive. The compensating capacitor (C_r) is selected so that:

$$|X_t|_{30\ \mathrm{MHz}} = |X_t|_{80\ \mathrm{MHz}}$$

The junction resistance r is constant. A broadband matching network connected between the junction and the antenna terminal is used to nearly cancel the junction reactance. The effectiveness of the broadband match improves as the ratio of Xt to r increases. If the Xt/r ratio at the band edge is equal to or greater than 1, an efficient match may be obtained.[1]

A computer program was written to optimize the output network. Given the following requirements:

1. r is a constant.
2. $|Xt|/r$ evaluated at the band edges must be greater than 1.
3. Qt as flat as possible with a minimum value of 59.
4. $|Xt|_{30\ \mathrm{MHz}}$ equal to $|Xt|_{80\ \mathrm{MHz}}$.
5. Zo_L equal 50 ohms.

[1] G. L. Matthaei, "Synthesis of Tchebycheff Impedance-Matching Networks, Filters, and Interstages," IRE Trans PGCT 3, pp 162-172 (September 1956).

Find the following parameters:

1. The characteristic impedance of the helical resonator (Zo_H).
2. The self-resonant frequency of the helical resonator (fo_H).
3. The quarter-wave resonant frequency of the connecting line (fo_L).
4. The value of r.
5. The angular position of the tap point (θ_t).
6. The value of the compensating capacitor (C_r).

Table 2-1. Optimum Parameters for Output Coupling Circuit.

ELEMENT	VALUE
Zo_H	295.7 ohms
fo_H	99.0 MHz
fo_L	105.2 MHz
r	6.9956 ohms
θ_t	17.933 degrees
C_r	[illegible].38 pF

The results of this analysis are presented in table 2-1. The analysis includes resonator and connecting line loss. The variation of Qt over the operating frequency range is shown in figure 2-4. Additional data in tabular form is included in appendix A. The data shows the values of Xo, X, X_{off}, Qt, Xt, and C, at 5-MHz intervals over the frequency range. The data shows the final value of $|Xt|/r$ at the band edge is 1.03. It may also be noted that the reactance of the on channel (X) may be neglected compared to the reactance of the off channels (Xo). The physical length of the connecting transmission lines using a Teflon dielectric is 19.95 inches, which is more than adequate to permit filter interconnection.

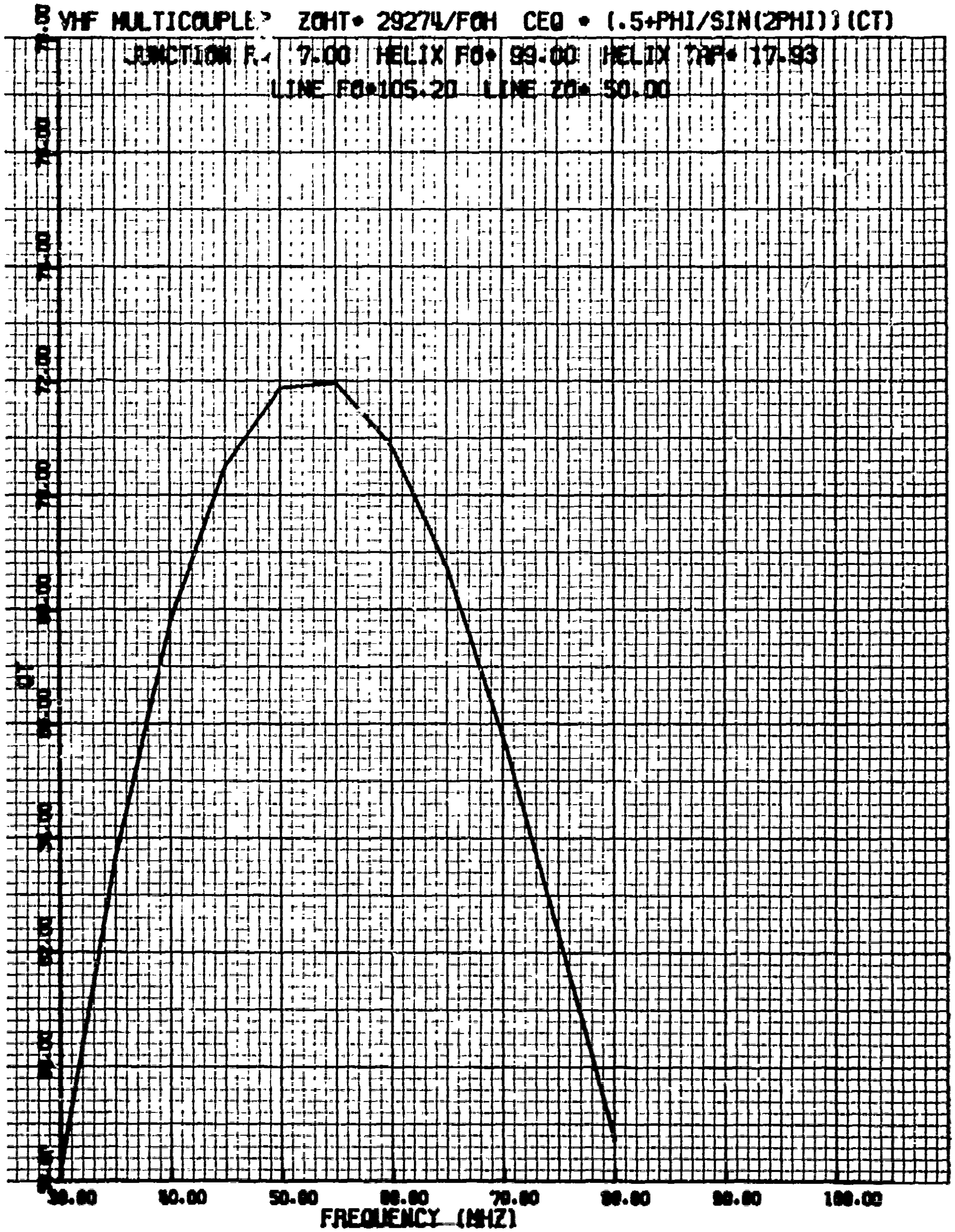


Figure 2-4. Terminal Q Variation With Frequency.

Matching Network Design

The matching network in this case performs two distinct functions. It provides broadband matching and impedance transformation. The matching network was computed using an existing program and provides an optimum design in regard to transmission loss across the operating frequency range. The program provided normalized low-pass prototype parameters for equal source and load resistances. The normalized values were manually transformed to the bandpass configuration. The transformer action required for unequal source and load resistances was computed using Norton's first transformation.

A very adequate broadband match was obtained using an $n = 3$ network. However, the required transformer action could not be obtained with physically realizable elements. It was necessary to use an $n = 5$ network to allow implementation of the impedance transformer action. The program which computed the element values was for a lossless network. The results are shown in table 3-1.

Table 3-1. Computed Matching Network Parameters.

CHARACTERISTIC	VALUE
Source resistance	R_S = 50 ohms
Equivalent circuit for load is most nearly parallel resonant, the element values are	R_L = 6.94882 ohms
	L_L = 22.7446 nH
	C_L = 429.698 pF
Load Q	Q_L = 0.992537
Source Q	Q_S = 0.582295
The coupling coefficients are	K12 = 0.904526
	K23 = 0.699890
	K34 = 0.748594
	K45 = 0.118990
Lower band edge	30 MHz
Upper band edge	80 MHz

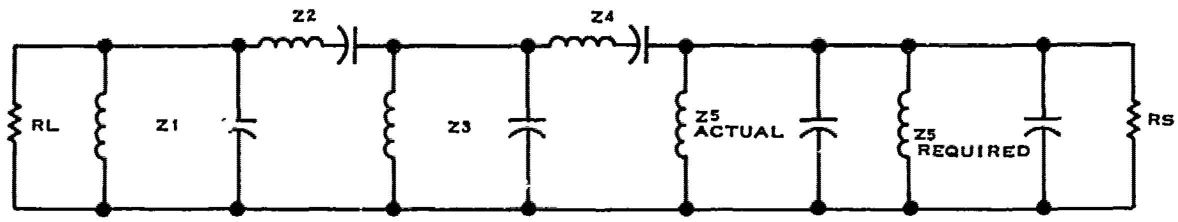
Table 3-1. Computed Matching Network Parameters (Cont).

CHARACTERISTIC	VALUE
Number of resonators	Five
Maximum transmission loss over band	0.025 dB
Maximum ripple	0.0094 dB
Geometric band center	48.9898 MHz

The data presented in table 3-1 is used as the basis for calculating the final network values. The procedure for arriving at the final values is presented in figure 3-1.

Using the network shown in figure 3-1, an analysis was performed to find the voltage and current rating of the capacitors and inductors comprising the network. Inductors were constructed and the Q of each measured. This value of Q was used to determine the power dissipation in each inductor. The input power into the network was assumed to be 500 watts. This represents a worst-case stress analysis of the network. The results of this analysis are presented in appendix B. A schematic of the complete matching network is shown in figure 3-2. Due to the high current levels, capacitor C2 is composed of three units in parallel and capacitor C3 is two units in parallel.

Measured inductor Q is approximately 150 for L1, 250 for L2, 275 for L3, and 300 for L4. The inductors are air-wound coils of heavy gauge bus wire. A layout of the matching network is shown in figure 3-3. The layout is such that capacitor and inductor lead length is held to an absolute minimum. Mutual coupling between the inductors is minimized by mounting them at right angles to each other and spacing them as far apart as practical.

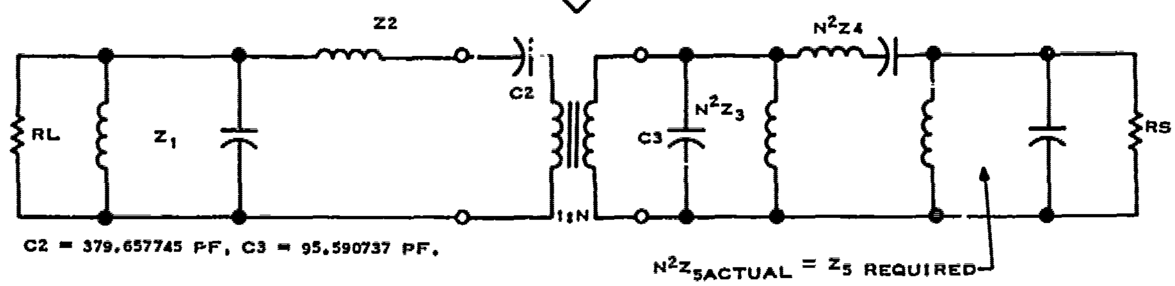


$$Z_1 = \frac{RL}{QL} = \frac{6.94882}{0.992537} = 7.001069\,\Omega, \quad Z_2 = \frac{Z_1}{(K12)^2} = \frac{7.001069}{(0.904526)^2} = 8.557014\,\Omega$$

$$Z_3 = Z_2(K_{23})^2 = (8.557014)(0.699890)^2 = 4.191619\,\Omega, \quad Z_4 = \frac{Z3}{(K_{34})^2} = \frac{4.191619}{(0.7485994)^2} = 7.479785\,\Omega$$

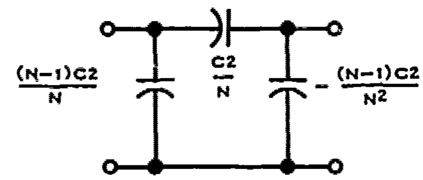
$$Z_{5\,\mathrm{ACTUAL}} = Z_4\,(K_{45})^2 = (7.479785)(1.18990)^2 = 10.590344, \quad Z_{5\,\mathrm{REQUIRED}} = \frac{RS}{QS} = \frac{50}{0.582295} = 85.867129\,\Omega$$

THE REQUIRED TURNS RATIO IS: $N = \sqrt{\dfrac{Z5\ \mathrm{REQUIRED}}{Z5\ \mathrm{ACTUAL}}} = \sqrt{\dfrac{85.867129}{10.590344}} = 2.847465$



C2 = 379.657745 PF, C3 = 95.590737 PF.

$N^2Z_3 = 33.985894\,\Omega \quad N^2Z4 = 60.646538\,\Omega$



$$\frac{C2}{N} = 133.331826\ \mathrm{PF}, \quad \frac{(N-1)C2}{N} = 246.325919\ \mathrm{PF}, \quad -\frac{(N-1)C2}{N^2} = -86.507084\ \mathrm{PF}.$$

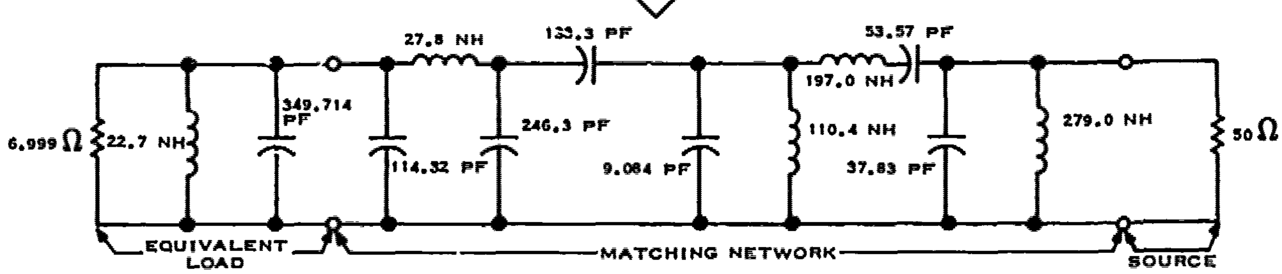


Figure 3-1. Reduction of Prototype to Final Network Values.

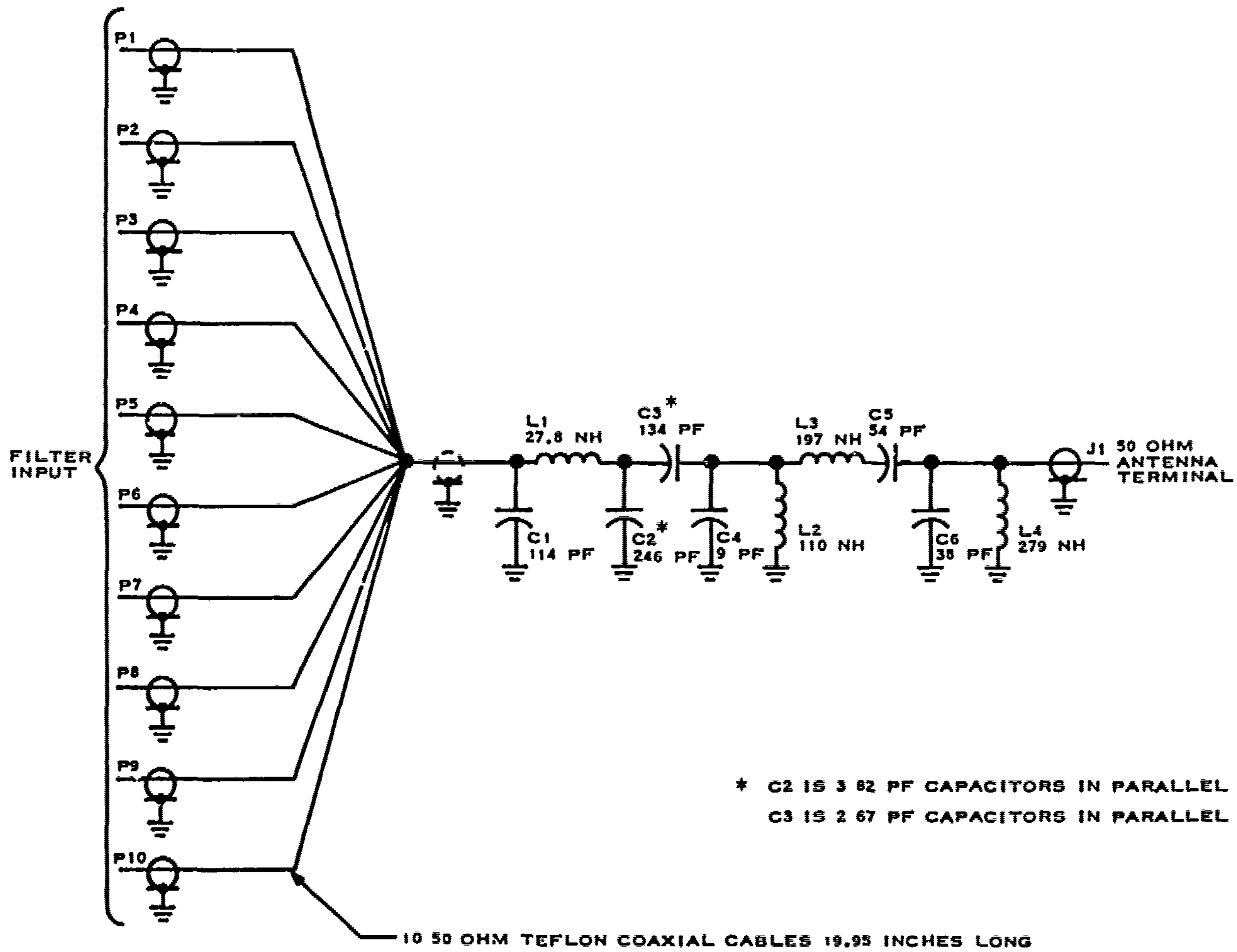


Figure 3-2. Matching Network Schematic.

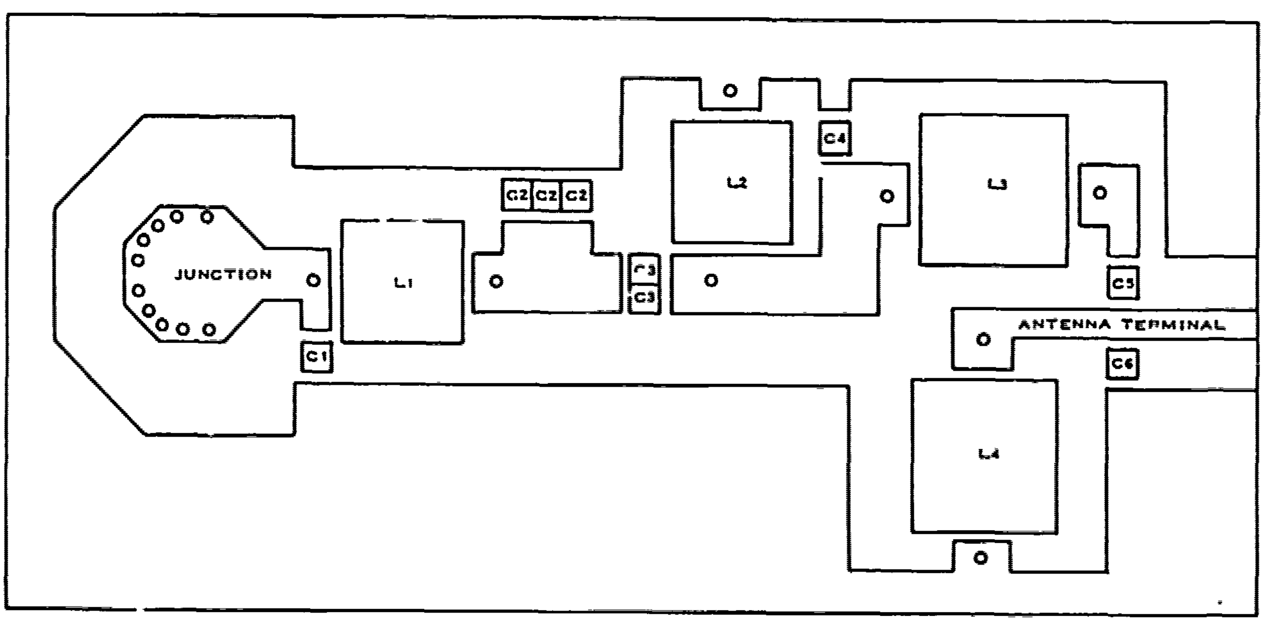
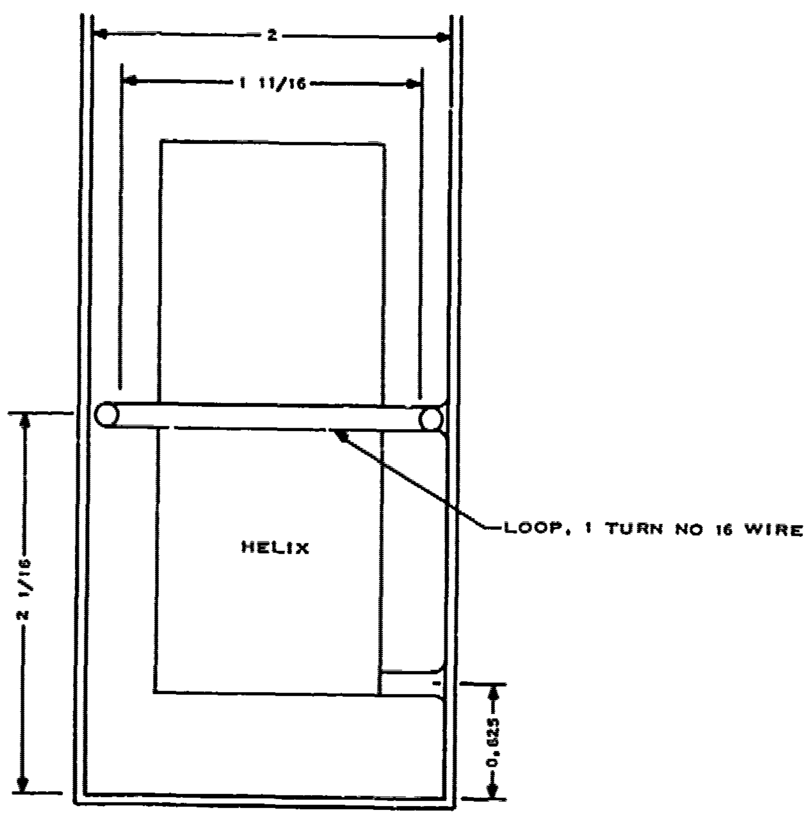


Figure 3-3. Matching Network Layout.

Input and Internal Couplings

As described in section 1, the couplings should remain as nearly constant as possible as the filter is tuned. The input coupling is in the form of a loop. Laboratory investigation showed that the flattest coupling could be obtained using loop coupling at the 50-ohm level (transceiver input terminal). Figure 4-1 presents the measured terminal Q for the configuration shown. This terminal Q shape is the best possible for a fixed structure.

F MHZ	QT
30	59.0
35	53.0
40	50.5
45	48.7
50	47.8
55	47.8
60	48.0
65	49.0
70	51.0
75	54.0
80	59.0



NOTE: LOOP GROUNDED TO SAME SURFACE AS HELIX
LOOP WOUND IN SAME DIRECTION AS HELIX

Figure 4-1. Measured Input Terminal Q.

The desired terminal Q is 59 to provide the required selectivity.

Aperture coupling is used for the two internal couplings. This form of coupling can be made to agree very closely with the desired shape. Figure 4-2 presents the measured coupling for the depicted configuration.

F MHZ	K
34.0	0.0166
45.0	0.0167
55.0	0.0167
65.0	0.0169
72.5	0.0168
80.0	0.0167

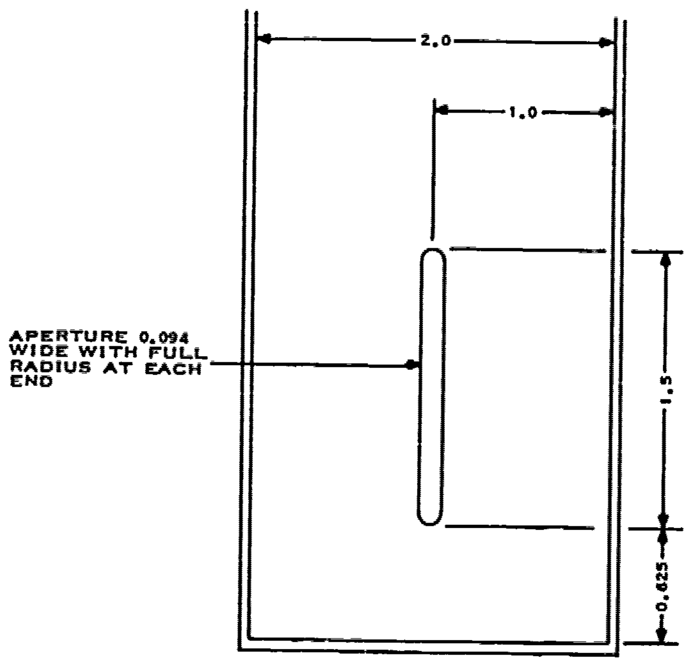


Figure 4-2. Measured Coupling Coefficient.

Overall Performance Analysis

An overall performance analysis was performed on the multicoupler. Input and output data is given in appendix C in tabular form. The computer analysis included computed and measured values from sections 2, 3, and 4, as input data. Circuit loss resistance was included for the elements of the matching network, filter, and interconnecting transmission lines. The filter was synchronously tuned at each node by the program. The more pertinent information is presented in graph form in the following figures.

Figure 5-1 shows the overall insertion loss of the multicoupler from a transceiver input terminal to the antenna terminal. The insertion loss is greatest at 30 MHz and decreases in value as the frequency is increased, due to increasing resonator unloaded Q.

Figure 5-2 presents the attenuation 5 percent above and below the operating frequency. The attenuation exceeds 40 dB in all areas except the 0.95 fo curve drops slightly below 40 dB at 30 MHz. Channel-to-channel attenuation is nearly 40 dB in all cases since a cochannel does not exist below 30 MHz. The specified attenuation will be achieved in the final design by slightly altering the internal couplings.

Figure 5-3 shows the input vswr (transceiver terminal) at the tuned operating frequency. The maximum input vswr does not exceed 1.35:1 over the 30- to 80-MHz frequency range. The vswr curve peaks at the middle of the vhf band and at the band edges. The increase in vswr at the band edges is due to the effect of the broadband matching network. The effectiveness of the matching system is poorest at the band edges. The peak in vswr at the middle of the vhf band is due to the mismatch in the input and output couplings. That is, the couplings deviate the greatest degree from the desired shape in this area. The input terminal Q is low and the output terminal Q is high in relation to the nominal design value.

Figure 5-4 gives the required value of tuning capacitors C1, C2, and C3. Capacitor C3 requires a higher value of capacity to tune out the effects of the output coupling. Capacitor C2 has the value shown; however, capacitor C1 will likely fall between the value of C2 and C3 in the actual filter. This is because the self-inductance of the input coupling loop was not taken into account in the analysis.

The performance analysis as presented in this section verifies that all of the specified requirements can be achieved.

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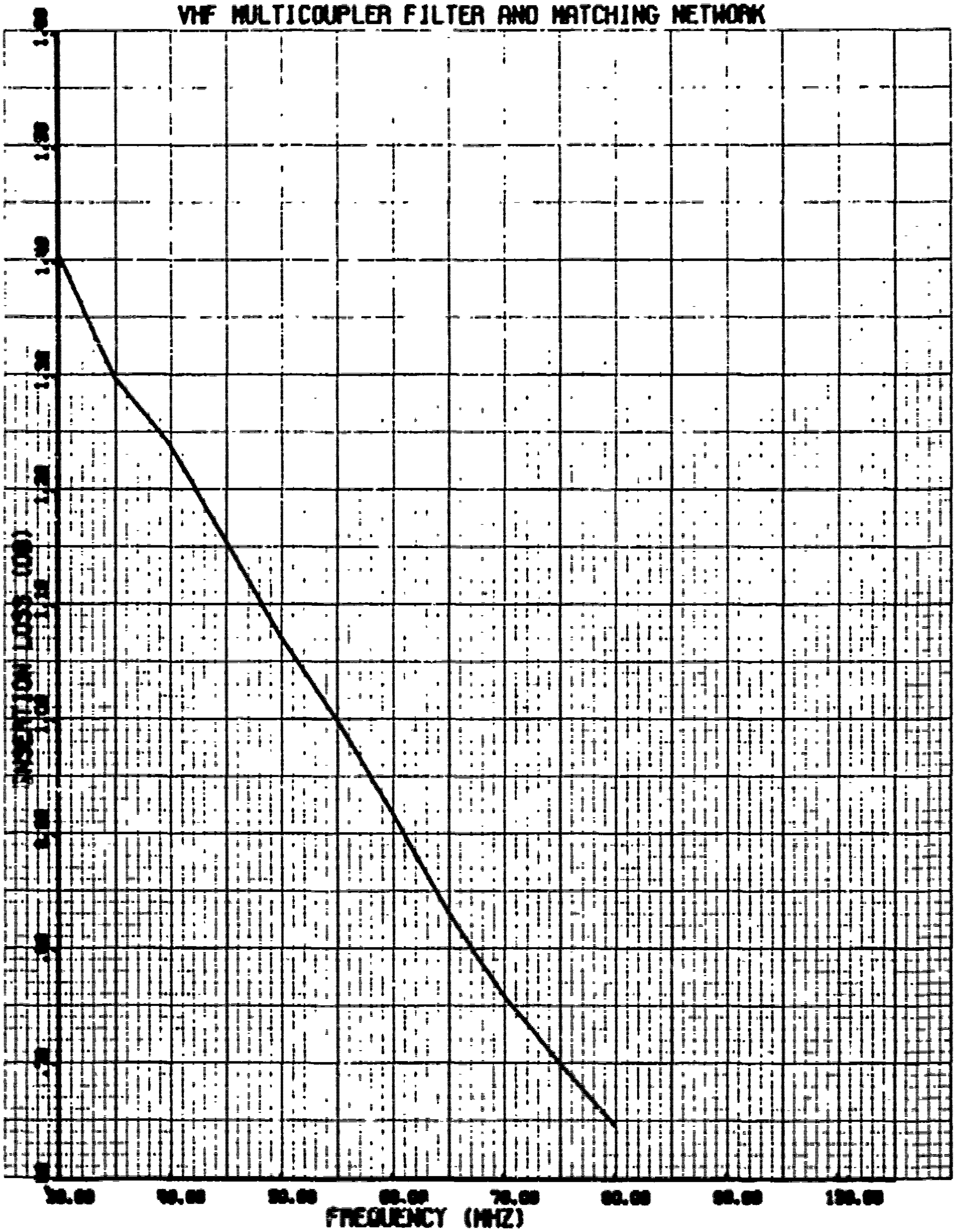

Figure 5-1. Total Multicoupler Insertion Loss.

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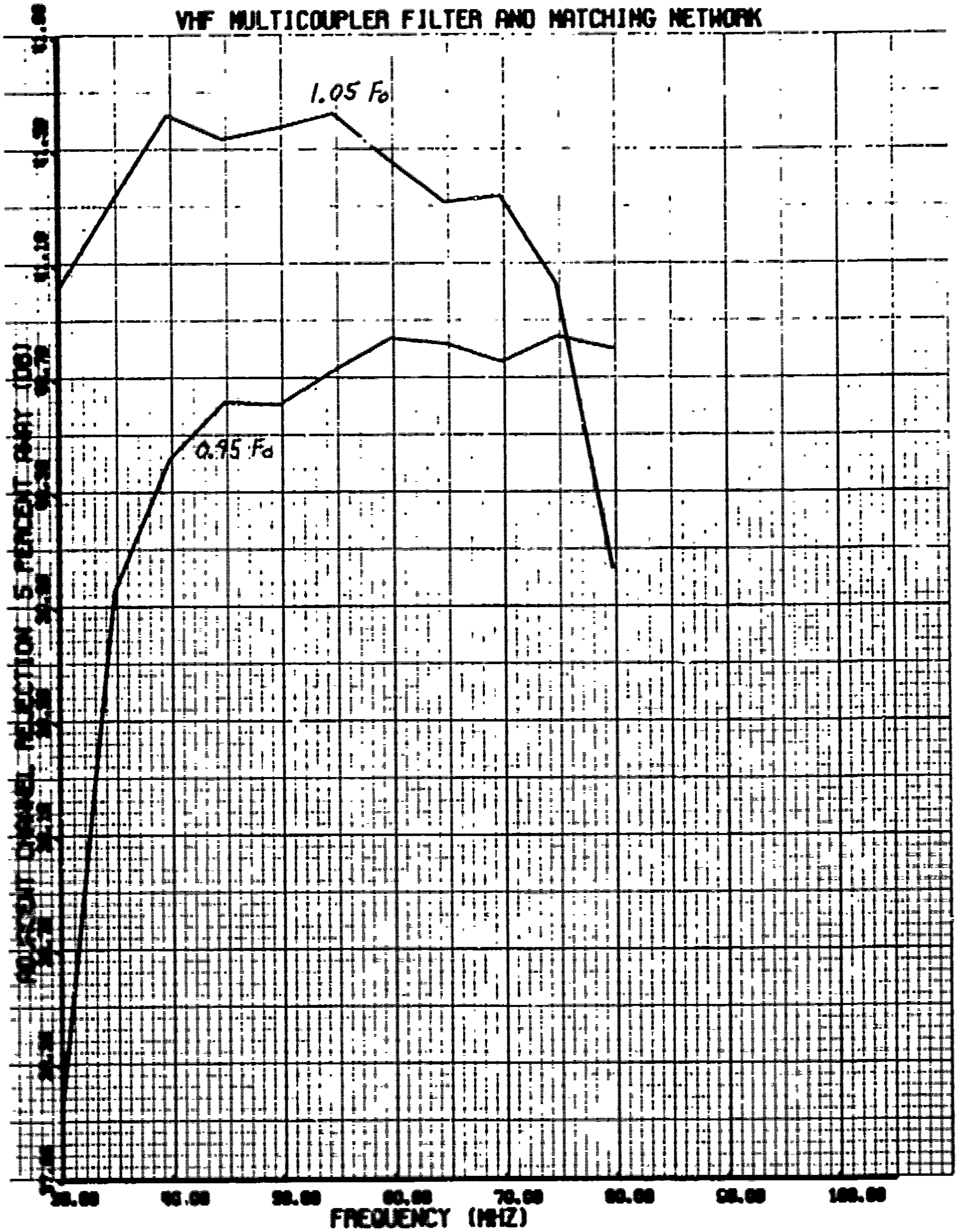

Figure 5-2. Attenuation at 5-Percent Frequency Spacings.

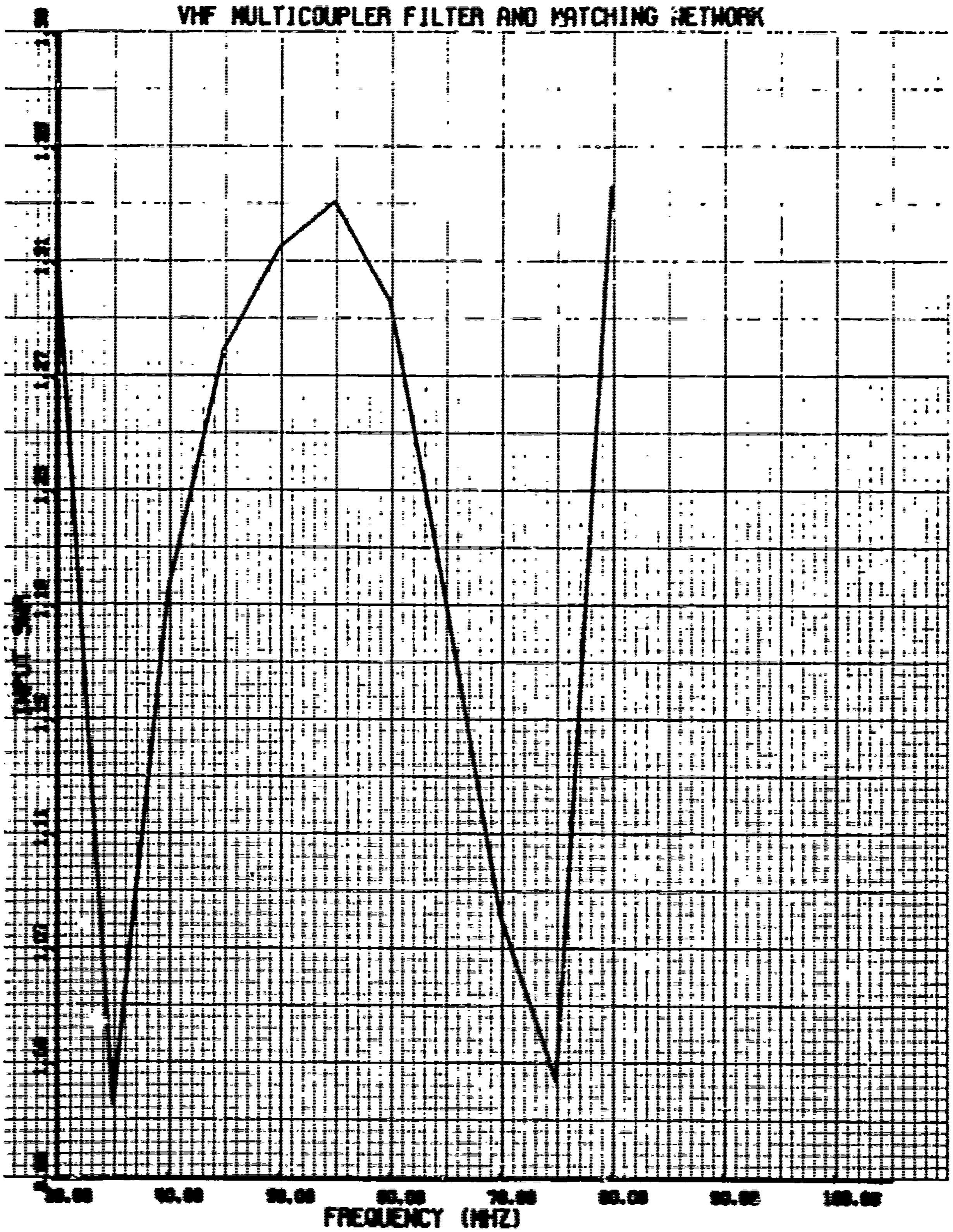

Figure 5-3. Input VSWR.

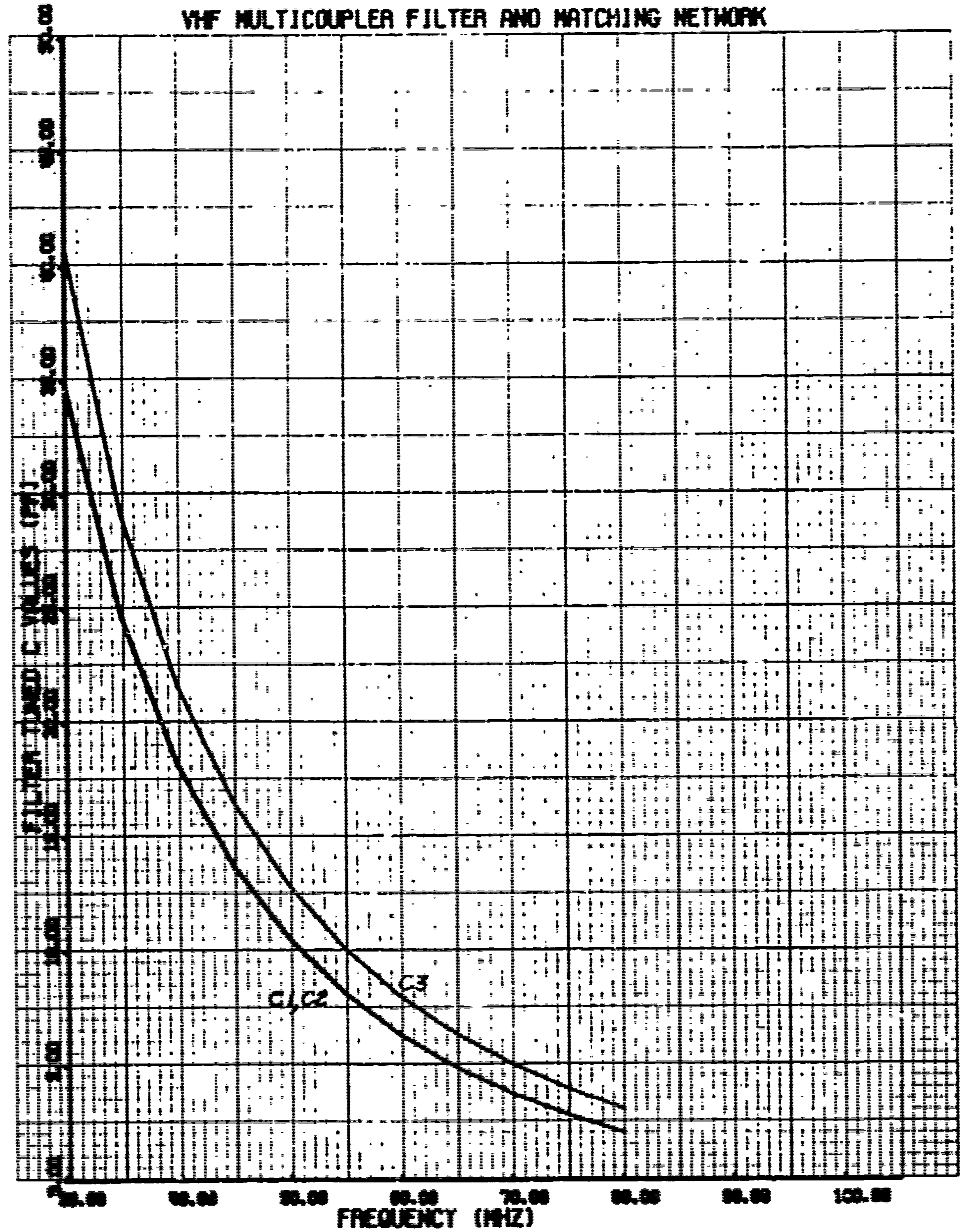

Figure 5-4. Tuning Capacitor Values.

Section 6

Filter Design

The design of the filter is the same as described in the original proposal. A 3-resonator filter provides the required performance. A schematic of the filter is shown in figure 6-1.

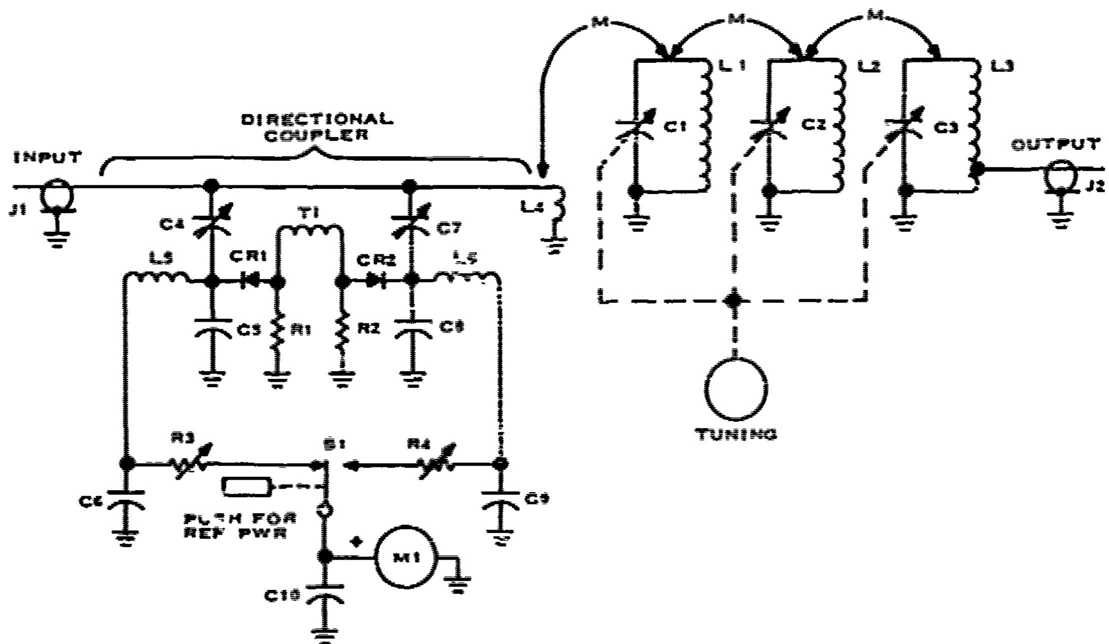

Figure 6-1. 30- to 80-MHz VHF Filter Schematic.

Helical resonators L1, L2, and L3 are mounted in 2-inch square enclosures. The helix proper consists of 7.33 turns of #6 wire. The outside diameter of the helix is 1.5 inches. The unloaded Q of the helical resonator has been measured. The Q is slightly above that predicted by the approximate formula: $Qu = 60S\sqrt{f}$. The output resonator is tapped at 1.61 turns from the shorted end of the helix. This connection forms the output terminal of the filter.

The resonators are coupled together by means of apertures in the resonator sidewalls as shown in figure 4-2. Input coupling is by means of a loop encircling input helix L1, as shown in figure 4-1.

The helical resonators are tuned by capacitors C1, C2, and C3. The voltage and capacity ranges of the tuning capacitors are tabulated in appendix C. Although the capacity and voltage ranges are slightly different for the three units, a single design will be used that will accommodate all three requirements. A preliminary tuning capacitor specification is presented in table 6-1.

Table 6-1. Preliminary Tuning Capacitor Specification.

CHARACTERISTIC	SPECIFICATION
Capacity range:	1.5 to 45 pF
Frequency range:	30 to 80 MHz
Capacitor Q:	5000 minimum
Voltage rating:	2500 volts peak rf
Current rating:	5.0 amperes rms
Temperature coefficient	0 ±50 PPM per °C
Size	
Length	1.0 inch maximum
Diameter	1.75 inch maximum
Type of mounting	Bushing mounted, total capacity range in 180° shaft rotation desirable.

A capacitor that meets the requirements given in table 6-1 has not been obtained to date. This represents the single major problem on this development. Nine capacitor vendors have been contacted in regard to this unit. Two vendors are presently working on preliminary designs. One unit is a Teflon device; the other employs an alumina dielectric. A sample capacitor was constructed in our laboratory using a polystyrene dielectric. The unit met most of the requirement except for low Q and extreme difficulties in fabrication. Parts are currently on order for a second unit having a Teflon dielectric and a different method of construction. It is felt that the capacitor design is within the reach of present technology; however, some experimentation will be required to find the most suitable dielectric material and design approach.

The directional coupler circuitry (located between the input terminal and input coupling loop) is in the breadboard stage. The design is straightforward and good results are

being obtained. Magnitude and phase compensation circuitry is currently being implemented. This will provide accurate forward and reflected power readings across the frequency range. The forward/reflected power meter is designed for 50 watts full scale.

One knob tuning of the filter is highly desirable from the standpoint of easy adjustment in the field. Also, a single tuning shaft would be ideal for an automatically tuned version of the multicoupler. As noted in section 5, the tuning capacitors do not have the same value of capacity at each frequency because of the self-reactance of the various couplings being different. The method for achieving one-knob tuning is depicted in figure 6-2. The central resonator, L2 and C2, is used as a "pilot" resonator, that is, no tracking adjustments are provided. The input resonator, L1 and C1, and the output resonator, L3 and C3, are made to track with the pilot resonator by means of an adjustable drive system that couples the three tuning capacitor shafts together.

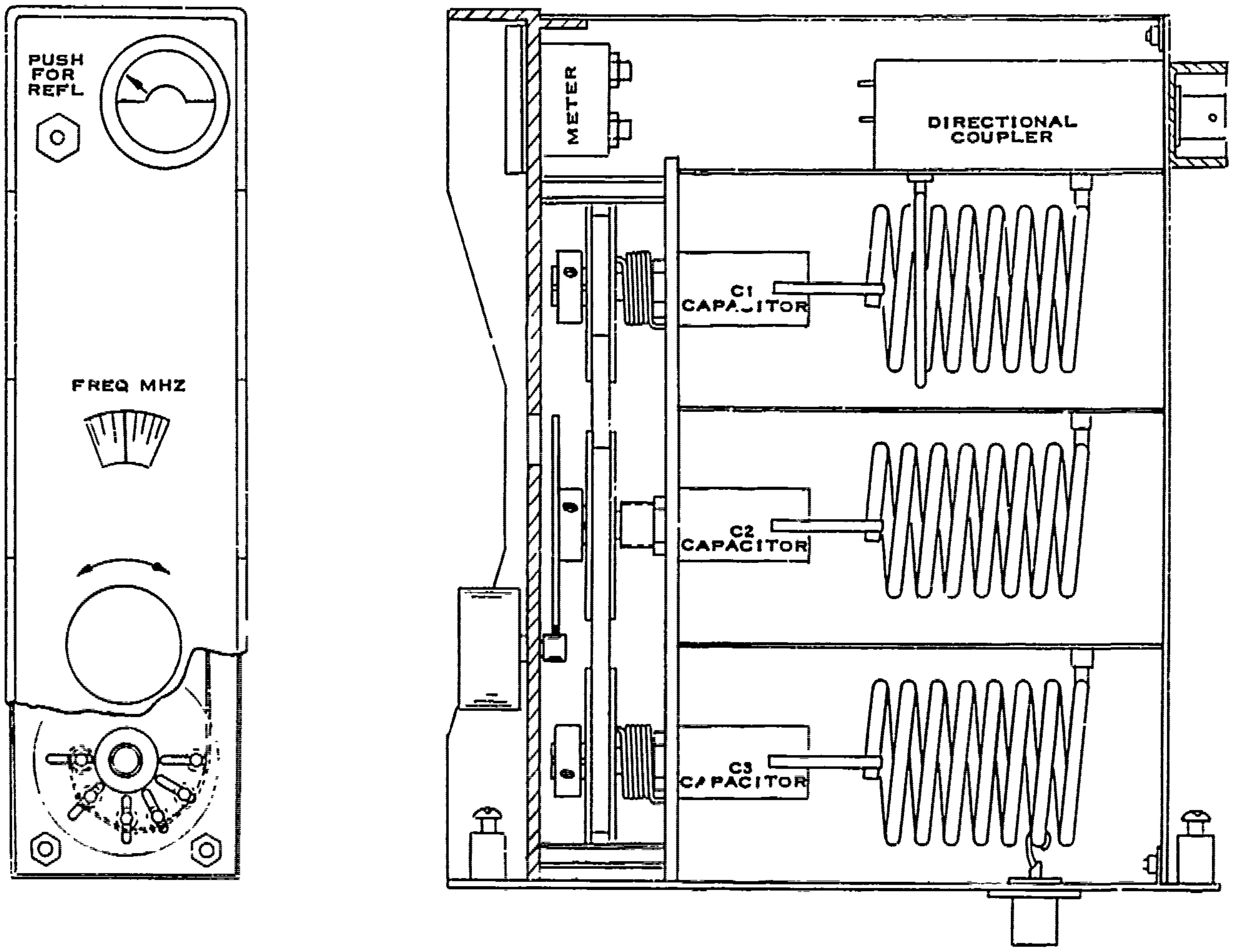

Figure 6-2. Internal Layout of the VHF Filter.

A drum is attached to each capacitor shaft. A thin metallic tape is used to drive the input and output capacitors from the drum on the central capacitor shaft. Adjustment screws in the input and output capacitor drums allow the effective radius to be adjusted, thus altering the tuning point of the input and output resonators with respect to the central resonator.

Initial tracking and testing of the vhf filter will be performed using a multicoupler simulator as shown in figure 6-3. This allows the testing to be accomplished on a single filter in a uniform 50-ohm system.

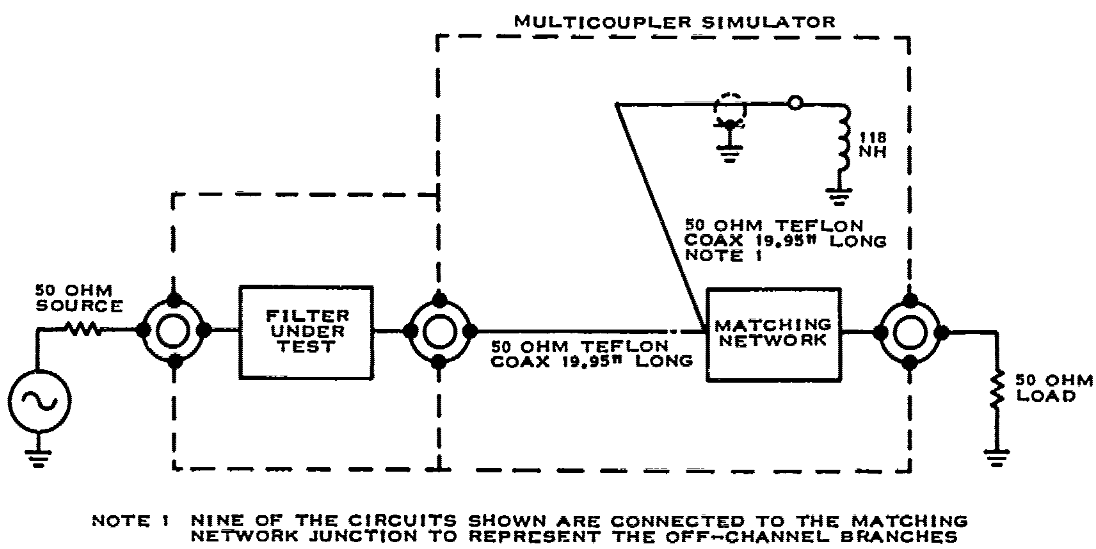

Figure 6-3. Multicoupler Simulator.

The simulator consists of a matching network, and connecting transmission lines as described in sections 2 and 3. The off-channel reactance of the nine dummy branches is simulated by a 118-nH inductor See Xoff data, appendix A.

Physical Configuration

The 10-channel vhf multicoupler is shown in figure 7-1. The multicoupler mounting frame provides a rigid surface for mounting the 10 tunable filters comprising the multicoupler. The right side of the frame has a carrying handle and the antenna connector. The front surface of the frame has a 5-percent frequency spacing chart to allow for rapid channel assignment under field conditions.

The interior of the mounting frame contains the matching network and interconnecting transmission lines. The transmission lines terminate in 10 "push-on" type coaxial connectors in the top of the mounting frame to accept the filter outputs.

Ten plug-in filters are attached to the top surface of the mounting frame. Each filter has four captive holddown screws. The front panel of the filter has a tuning knob, frequency readout dial, forward and reflected power meter, push-for-reflected-power switch, and a nameplate. The front panel controls are protected by raised lips at the four corners of the panel. The filter input connector is located at the top rear of each filter. A connector guard is provided to prevent damage.

The filter input connectors are type BNC; the antenna connector is a type N. Overall size of the multicoupler is 21.5 inches long by 9 inches high by 7 inches deep.

physical configuration

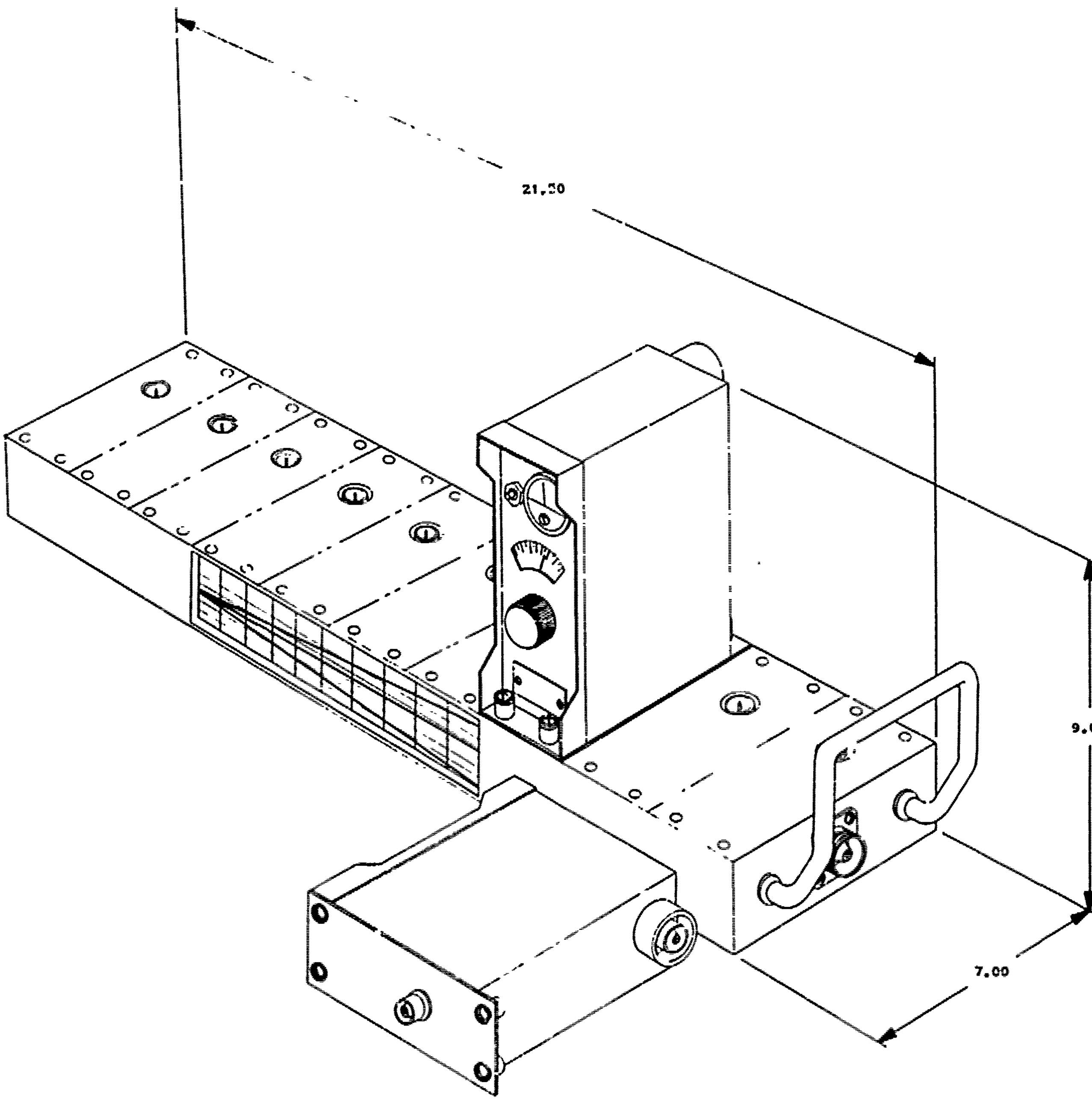

Figure 7-1. 10-Channel VHF Multicoupler.

Conclusion

The following accomplishments have been made during this report period.

1. Theoretical design of all assemblies comprising the multicoupler has been completed.
2. Layout of matching network circuit card is complete.
3. Matching network inductors have been designed and measured.
4. Capacitors for the matching network have been specified and are on order (18 October).
5. Helical resonators for the filter have been designed and tested.
6. Input, internal, and output couplings have been constructed and evaluated.
7. Directional coupler breadboard circuitry is complete.
8. Tuning capacitor requirements are defined and a suitable vendor is being sought.
9. Overall mechanical design concept for the multicoupler is approximately 50 percent complete.

During the next period the following items are to be accomplished.

1. Obtain tuning capacitor.
2. Complete mechanical layout.
3. Construct and evaluate filter and matching network.
4. Construct two developmental models.
5. Test models and prepare final technical report.
6. Prepare evaluation report.

Appendix A

Output Coupling Network Data

Output Coupling Network Data

fMHz	Xo OHMS	X OHMS	Xoff OHMS	Qt	Xt OHMS	C pF
30	+58.56	$+0.352 \times 10^{-15}$	+22.09	58.29	+7.214	40.06
35	+77.72	$+0.363 \times 10^{-15}$	+25.79	63.69	+10.182	28.72
40	+106.2	$+0.138 \times 10^{-14}$	+29.52	67.78	+15.471	21.35
45	+155.2	-0.400×10^{-15}	+33.25	70.52	+28.265	16.28
50	+264.5	-0.758×10^{-16}	+37.01	71.91	+112.6	12.64
55	+794.0	-0.366×10^{-15}	+40.78	72.00	-62.815	9.94
60	-924.3	$+0.684 \times 10^{-15}$	+44.57	70.89	-25.122	7.87
65	-292.3	$+0.461 \times 10^{-15}$	+48.39	68.76	-15.766	6.25
70	-172.4	$+0.661 \times 10^{-16}$	+52.23	65.80	-11.448	4.95
75	-120.8	$+0.492 \times 10^{-15}$	+56.10	62.32	-8.914	3.88
80	-91.44	$+0.479 \times 10^{-16}$	+60.00	58.72	-7.214	2.99

Appendix B

Matching Network Stress Analysis

Matching Network Stress Analysis, Input Power 500 Watts

fMHz	PEAK CAPACITOR VOLTAGE, VOLTS					
	C1	C2	C3	C4	C5	C6
30	90.294	165.31	391.14	278.71	505.94	219.20
35	82.455	143.06	275.99	236.19	403.54	220.38
40	78.611	136.44	230.21	224.35	337.46	220.64
45	78.398	133.15	199.58	222.12	293.32	220.70
50	78.782	134.05	176.11	221.98	262.69	220.66
55	78.423	136.46	158.47	222.47	240.71	220.52
60	78.787	138.77	145.74	224.48	224.50	220.29
65	80.671	141.55	136.85	229.64	212.23	220.00
70	82.884	146.84	130.68	239.60	202.70	219.62
75	84.497	157.23	126.24	255.52	195.01	219.01
80	89.873	174.65	122.64	277.69	188.40	217.90

fMHz	RMS CAPACITOR CURRENT, AMPERES					
	C1	C2	C3	C4	C5	C6
30	1.3760	5.4282	6.9520	0.33750	3.6129	1.1056
35	1.4660	5.4805	5.7230	0.33367	3.3620	1.2968
40	1.5973	5.9735	5.4556	0.36223	3.2131	1.4838
45	1.7921	6.5584	5.3211	0.40346	3.1419	1.6697
50	2.0010	7.3366	5.2170	0.44799	3.1264	1.8549
55	2.1911	8.2149	5.1637	0.49389	3.1514	2.0391
60	2.4014	9.1138	5.1807	0.54365	3.2063	2.2221
65	2.6637	10.071	5.2700	0.60249	3.2837	2.4041
70	2.9473	11.251	5.4197	0.67697	3.3775	2.5846
75	3.2192	12.907	5.6093	0.77352	3.4815	2.7615
80	3.6524	15.293	5.8128	0.89669	3.5877	2.9307

fMHz	PEAK INDUCTOR VOLTAGE, VOLTS			
	L1	L2	L3	L4
30	86.947	278.71	169.73	219.20
35	84.363	236.19	205.98	220.38
40	92.424	224.35	224.98	220.64
45	100.72	222.12	247.49	220.70
50	110.85	221.98	273.64	220.66
55	123.64	222.47	303.40	220.52
60	138.07	224.48	336.75	220.29
65	153.08	229.64	373.62	220.00
70	169.68	239.60	413.86	219.62
75	192.69	255.52	457.07	219.01
80	230.98	277.69	502.41	217.90

Matching Network Stress Analysis, Input Power 500 Watts (Cont)

fMHz	RMS INDUCTOR CURRENT, AMPERES			
	L1	L2	L3	L4
30	11.734	9.4713	3.6129	2.9481
35	9.7592	6.8796	3.3620	2.5406
40	9.3552	5.7180	3.2131	2.2256
45	9.0623	5.0321	3.1419	1.9789
50	8.9764	4.5259	3.1264	1.7807
55	9.1018	4.1237	3.1514	1.6177
60	9.3168	3.8142	3.2063	1.4814
65	9.5350	3.6016	3.2837	1.3657
70	9.8143	3.4894	3.3775	1.2659
75	10.402	3.4732	3.4815	1.1782
80	11.690	3.5387	3.5877	1.0990
fMHz	**INDUCTOR POWER DISSIPATION, WATTS**			
	L1	L2	L3	L4
30	5.5502	10.371	2.3085	1.1425
35	4.4788	6.3841	2.3321	0.9899
40	4.7036	5.0402	2.4344	0.8682
45	4.9654	4.3916	2.6187	0.7722
50	5.4130	3.9471	2.8811	0.6947
55	6.1219	3.6044	3.2199	0.6307
60	6.9975	3.3640	3.6361	0.5770
65	7.9400	3.2495	4.1316	0.5312
70	9.0590	3.2848	4.7074	0.4915
75	10.904	3.4868	5.3589	0.4562
80	14.688	3.8608	6.0701	0.4234

Appendix C

Overall Performance Analysis

INPUT DATA

For the Matching Network:

C1 = 114.32 pF
C2 = 246.33 pF
C3 = 133.33 pF
C4 = 9.0836 pF
C5 = 53.568 pF
C6 = 37.835 pF
L1 = 27.799 nH
L2 = 110.41 nH
L3 = 197.03 nH
L4 = 278.96 nH
QL1 = 150
QL2 = 250
QL3 = 275
QL4 = 300
Antenna terminal impedance = 50 ohms

For the Connecting Transmission Lines:

Z_{o_L} = 50 ohms
Attenuation per 100 feet = 0.340 dB
Velocity factor = 69.5 percent
f_{o_L} = 105.20 MHz
Length = 1.6252 feet

For the Filter:

Z_{o_H} = 295.70 ohms
K_{12}, K_{23} = 0.01587
Output resonator tap point (θ_t) = 17.933 degrees
Tuning capacitor Q (C1, C2, and C3) = 5000
Helix Q = $120\sqrt{f_o}$
Input terminal Q = Distribution shown in figure 4-1
Power input = 50 watts
Filter input source impedance = 50 ohms

OUTPUT DATA

fMHz	TOTAL INSERTION LOSS (dB)	INPUT VSWR	ATTENUATION AT 0.95 fo (dB)	ATTENUATION AT 1.05 fo (dB)	MATCHING NETWORK EFFICIENCY (%)	TOTAL EFFICIENCY (%)
30	1.5077	1.3215	38.262	41.119	96.868	70.669
35	1.4004	1.0261	40.065	41.429	97.678	72.438
40	1.3419	1.2059	40.527	41.734	97.851	73.420
45	1.2591	1.2902	40.726	41.650	97.896	74.832
50	1.1757	1.3259	40.718	41.690	97.863	76.284
55	1.1035	1.3419	40.839	41.740	97.754	77.562
60	1.0222	1.3069	40.949	41.576	97.587	79.029
65	0.9348	1.2053	40.930	41.428	97.377	80.635
70	0.8618	1.0924	40.866	41.449	97.099	82.001
75	0.8031	1.0343	40.955	41.143	96.658	83.117
80	0.7479	1.3470	40.913	40.144	95.840	84.180

fMHz	PEAK VOLTAGE RESONATOR 1 (volts)	PEAK VOLTAGE RESONATOR 2 (volts)	PEAK VOLTAGE RESONATOR 3 (volts)	POWER DISSIPATION RESONATOR 1 (watts)	POWER DISSIPATION RESONATOR 2 (watts)	POWER DISSIPATION RESONATOR 3 (watts)
30	792.26	1038.7	688.39	3.5431	6.0905	2.7282
35	943.95	1008.2	852.73	3.9051	4.4543	3.2572
40	1067.0	1016.3	983.60	3.9668	3.5986	3.4545
45	1148.2	1065.8	1068.9	3.7092	3.1961	3.3042
50	1213.4	1124.7	1137.9	3.3767	2.9010	3.0631
55	1277.2	1177.6	1206.4	3.0621	2.6031	2.8297
60	1314.9	1250.4	1248.2	2.6543	2.4003	2.4903
65	1322.0	1348.7	1259.3	2.1810	2.2698	2.0737
70	1324.7	1445.3	1267.3	1.7571	2.0918	1.6999
75	1317.4	1546.4	1266.5	1.3637	1.8790	1.3483
80	1234.3	1743.3	1188.9	0.9049	1.8050	0.9144

OUTPUT DATA (Cont)

fMHz	PARALLEL RESIST-ANCE RESO-NATOR 1 (k Ω)	PARALLEL RESIST-ANCE RESO-NATOR 2 (k Ω)	PARALLEL RESIST-ANCE RESO-NATOR 3 (k Ω)	TUNING CAPACITY C1 AND C2 (pF)	TUNING CAPACITY C3 (pF)	POWER DELIVERED TO ANTENNA (watts)
30	8.2971	11.616	5.8715	34.791	40.747	35.335
35	8.6868	11.028	8.7339	24.777	29.180	36.219
40	9.4443	11.222	11.403	18.269	21.708	36.710
45	10.221	12.274	13.261	13.798	16.568	37.416
50	11.108	13.570	14.813	10.590	12.889	38.142
55	12.160	14.777	16.418	8.2072	10.153	38.781
60	13.233	16.516	17.338	6.3840	8.0574	39.514
65	14.504	19.024	17.412	4.9540	6.4175	40.317
70	16.069	21.658	17.404	3.8074	5.1068	41.001
75	17.957	24.591	17.158	2.8698	4.0324	41.559
80	20.529	30.959	14.950	2.0888	3.1406	42.090